

Power Lines and the Geomagnetic Field

Abraham R. Liboff and Bruce R. McLeod

Department of Physics, Oakland University, Rochester, Michigan (A.R.L.); Department of Electrical Engineering, Montana State University, Bozeman, Montana (B.R.M.)

The metric of prime interest in power line epidemiological studies has been AC magnetic intensity. To consider also possible geomagnetic involvement, the orientation of a long straight power line is examined relative to a uniform geomagnetic field (GMF) with dip angle α . An expression is derived for the component of the total GMF that is parallel, at an elevation β , to the circuital magnetic field that surrounds the line. This component is a function of the angles α and β , the total geomagnetic intensity B_T , and the angle θ between the axis of the power line and magnetic north. Plotting these geomagnetic parameters for known leukemia residences allows one to test for possible ion cyclotron resonance or other GMF interactions. This approach, in principle, is an easy addition to existing or planned studies, because residential access is not required to obtain local values for α , β , θ , and B_T . We recommend including these parameters in the design of epidemiological studies examining power line fields and childhood leukemia. ©1995 Wiley-Liss, Inc.

Key words: geomagnetic metric, ion cyclotron resonance, epidemiological design, power line orientation, childhood leukemia

INTRODUCTION

The various epidemiological reports [Wertheimer and Leeper, 1979; Savitz et al., 1988; London et al., 1991; Feychting and Ahlbom, 1992] linking power line exposures to childhood leukemia remain unexplained. In principle, one can design epidemiological studies around specific magnetic parameters to test proposed explanations. Faraday induction mechanisms would be expected to result in stronger correlations with increasing AC field strength and/or more frequent transients. Another proposed interaction mechanism involves ion cyclotron resonance (ICR) [Liboff, 1985]. Certain combinations of DC magnetic field intensity and AC magnetic field frequency presumably affect the transport of specific ions (Ca^{2+} , Mg^{2+} , K^+ , etc.) and thereby cause physiological change. We recently reported [Liboff et al., 1993] that human lymphoma cell culture proliferates more rapidly when exposed to parallel combinations of 60 Hz and static 511 mG (51.1 μT) magnetic fields. This combination, one of the ICR harmonic conditions for K^+ , is of some interest; the 511 mG field intensity is common to much of the United States.

It is important to realize that identifying any metric tied to the GMF, resonance or otherwise, might possibly be the basis for a rational mitigation of power line effects. It has been suggested [Liboff, 1987; Liboff et al., 1989a,b; Wertheimer et al., 1990; Blackman and Most, 1993] that there may be “allowed” values for

ambient 60 Hz power magnetic fields that are dependent on the GMF. It is conceivable that variables such as power line direction could be used in the design of epidemiological studies to test whether ICR interactions underlie the power line/leukemia connection. Bowman et al. [1994] attempted to relate a small subset of the childhood leukemia database established by London et al. [1991] in Los Angeles to the GMF. Using 380 and 506 mG, two 60 Hz resonances predicted on the basis of work by Lednev [1991] for calcium ions, Bowman et al. found modest indications that the latter DC field, 506 mG, correlated with leukemia. It is likely that the approximate nature of this calculation would have also yielded the same “marginal significance” had the potassium ICR value of 511 mG been used in the analysis instead of 506 mG.

There is also some question regarding the validity of claiming “resonance” when merely using the total magnetostatic field in a 60 Hz environment without regard to the relative orientation of the DC and AC vectors. Any resulting correlation necessarily reflects the putative resonant combinations of the total DC field, B_T ,

Received for review July 21, 1994; revision received October 21, 1994.

Address reprint requests to A.R. Liboff, Department of Physics, Oakland University, Rochester, MI 48309.

and the parallel component of the AC field at each site. However, these AC components will not be the same from site to site, so this technique tends to average out any functional dependence on AC intensity. Various ICR reports, both experimental [Smith et al., 1987; Rozek et al., 1987; Liboff et al., 1989a,b] and theoretical [Lednev, 1991], have involved the AC intensity as an important functional parameter.

In general, to determine the resonance conditions that can result from the combined presence of the GMF and an ambient 60 Hz magnetic field, one can find either the component of the total GMF parallel to the 60 Hz magnetic field vector or that of the AC field parallel to B_T . For a given value of B_T and a given frequency, these two choices will not result in the same resonance condition. That is, for the same charge-to-mass ratio, the ICR frequency will be different when B_T is used and when a component of B_T is used.

In the following, we elect to find the parallel component of B_T on the 60 Hz magnetic field vector: The mathematics is simpler, the metric is different from the 60 Hz magnetic intensity universally employed by the epidemiological community, and the result is framed in terms of the GMF.

THE PARALLEL GEOMAGNETIC COMPONENT

We represent a power line as a long horizontal wire carrying a constant AC current. The total GMF intensity, B_T , is assumed to be uniform in the vicinity of this line and has an inclination from the horizontal (dip angle) given by α . The power line makes an angle, θ , with geomagnetic north. We first restrict θ to 90° , thereby considering only those AC magnetic fields that lie in the vertical plane containing B_T . In this case the component of B_T parallel to the circuital AC field at the elevation β (Fig. 1) is

$$B' = B_T \cos \delta, \quad (1)$$

where δ is the angle between B_T and the AC field B_{AC} . It is not difficult to show that $\delta = 90^\circ - (\alpha + \beta)$, whence we obtain

$$B' = B_T (\sin \alpha \cos \beta + \cos \alpha \sin \beta). \quad (2)$$

This result can be generalized for all power line orientations. For power line directions other than $\theta = 90^\circ$ (EW), the first term in Equation 2 is unchanged, but the second term, reflecting the horizontal component, must be corrected by $\sin \theta$. For any other compass heading, θ , the component B of the total GMF vector B_T that is

parallel to the circuital AC field at an elevation angle θ , is given by

$$B = B_T (\sin \alpha \cos \beta + \cos \alpha \sin \beta \sin \theta). \quad (3)$$

DISCUSSION

The four variables B_T , α , β , and θ in Equation 3 are readily obtained in practice. The values of total GMF intensity B_T and inclination α in the United States and around the world are published as charts by the U.S. Geological Survey [1985] on a continuing basis. The angle θ that any given power line makes with magnetic north can be measured with a simple compass. For regions that are flat, the elevation of a line relative to a residence is determined by finding the (horizontal) perpendicular distance to the line, d , and using the relation $\tan \beta = h/d$, where h is the height of the line (Fig. 1).

Assuming a dip angle common to much of the northern United States, $\alpha = 70^\circ$, the fraction B/B_T of total GMF parallel to the AC magnetic field vector is plotted in Figure 2 as a function of elevation, from $\beta = 0^\circ$ (far from the line) to $\beta = 90^\circ$ (directly beneath the line). Five different orientations, in the range $\theta = 0^\circ$ to 90° , are shown. One sees that the possibility of any one value

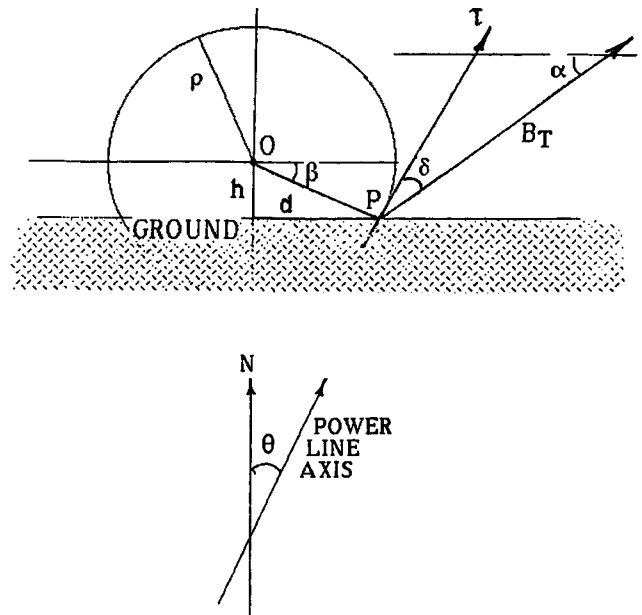


Fig. 1. View along the power line axis, centered at O. The circle of radius p corresponds to one value of the AC circuital magnetic field intensity about this axis. The angle of elevation of the line from a point P is β . The direction τ is along the AC magnetic field. For $\theta = 90^\circ$, the line is in the geomagnetic EW direction, and the total GMF B_T is in the plane of the page.

of B occurring is dependent on both power line orientation and elevation. The total GMF intensity B_T in the United States (excluding Hawaii) varies from about 470 mG in Florida to 600 mG in Minnesota. The third and fifth ICR harmonics of the K^+ ion at 60 Hz, 510.6 and 306.4 mG, respectively, correspond in Minnesota to B/B_T values of 0.851 and 0.511.

This restriction is greater for smaller dip angles. For Figure 3 we use the GMF characteristics found in the Los Angeles area ($\alpha = 59^\circ$ and $B_T = 490$ mG) to show that the third harmonic of the K^+ ICR will not be found there (except as it might occur from magnetostatic fields not connected to the GMF).

Figure 4 shows the values of β and B_T that can give rise to the third and fifth ICR harmonics for K^+ . The range of B_T , from 470 mG to 600 mG, covers all the possible ways in the continental United States in which 510.6 and 306.4 mG can occur as DC fields parallel to 60 Hz AC fields emanating from power lines. This plot can also be thought of as a locus that sets constraints on the potential for leukemia, if leukemia is, in fact, connected to K^+ ICR. For example, one might superimpose the set of parameters α , β , θ , and B_T for all residences where childhood leukemia has been recorded directly onto plots such as that in Figure 4 to test the functional character of the distribution of cases. Note that this approach could unambiguously demonstrate the involvement of magnetic fields and therefore wire code configuration. This approach might also help in explaining the lack of correlation of spot magnetic measurements of the AC magnetic field with childhood leukemia.

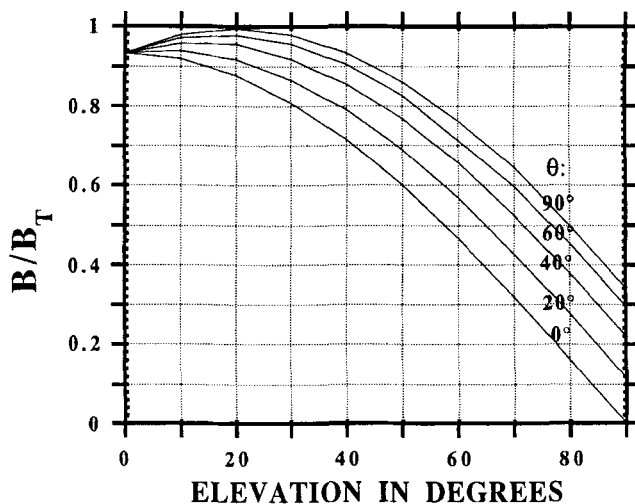


Fig. 2. Fraction of B_T parallel to B_{AC} as a function of the angle of elevation, β , for five different orientations of the power line. Dip angle is assumed to be 70° .

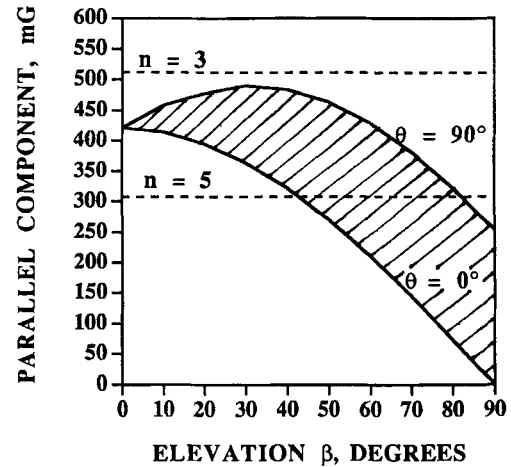


Fig. 3. Range of GMF components parallel to B_{AC} for the Los Angeles region, for power line orientations between $\theta = 0^\circ$ and 90° . Although the third K^+ ICR harmonic at 60 Hz (510.6 mG) cannot occur in this area, one would expect to find the fifth harmonic (306.4 mG).

The approach used for Figure 4 can be applied to determine appropriate parallel components of the GMF at any geographical point, not only within the United States but anywhere in the world. Although the GMF values occurring in the Nordic countries and in Australia are not radically different from those in the United States, the power source frequency is only 50 Hz, reducing the third and fifth ICR harmonics for K^+ to 425.5 and 255.3 mG, respectively. In Figure 5 we show the

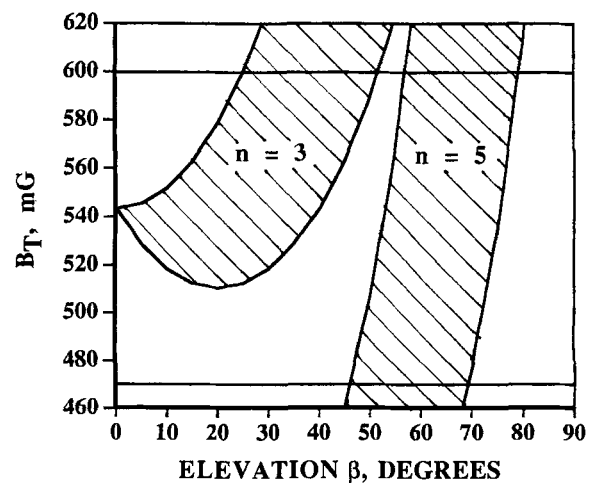


Fig. 4. Locus of values for β and B_T that can give rise to the third and fifth ICR harmonics for K^+ in the continental United States. Dip angle is assumed to be 70° .

possible ways in which these harmonics can occur at 50 Hz. The ranges of B_T in the United Kingdom and in Japan are both rather narrow (480–500 mG and 460–500 mG, respectively [Peddie, 1993]) compared to those in the United States and Scandinavia. Note that the likelihood of K^+ ICR conditions is enhanced for these lower ranges at 50 Hz relative to the same values of B_T in the United States at 60 Hz.

Although our example uses a very specific ICR condition, it is clear that the potential involvement of other types of resonances (e.g., Ca^{2+} or models in which GMF components are perpendicular to the AC field) in the epidemiological results can be similarly explored. In principle, the same analysis can also be performed for power line configurations [Kaune and Zaffanella, 1992] that do not conform to the simple circuit model for AC magnetic fields that we have assumed. It is likely that the interior GMF will be distorted by building materials and local magnetic anomalies [Swanson, 1994] and that the interior AC magnetic field may reflect sources other than nearby power lines.

Nevertheless, the potential advantages of this approach are 1) that the variables determining the mean parallel component of the GMF at a given residence can be obtained without requiring access to the home and 2) that it allows one to study, en masse, all previously recorded childhood leukemia cases for homes for which these variables are available. We therefore suggest that these four variables be determined at each site for epidemiological studies probing the relation of power lines to childhood leukemia, as a relatively straightforward means of evaluating the potential role of resonance effects tied to the GMF.

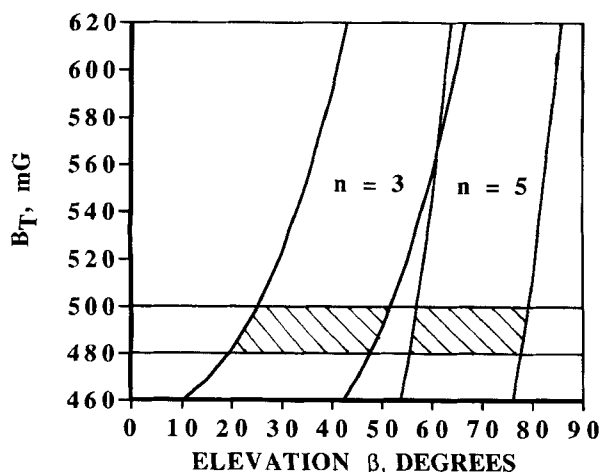


Fig. 5. Locus of values for β and B_T that can give rise to the third and fifth K^+ ICR harmonics for countries employing 50 Hz electric power. Dip angle is taken as 70° . Horizontal lines at 480 and 500 mG encompass the range of B_T in the United Kingdom.

REFERENCES

- Blackman CF, Most B (1993): A scheme for incorporating DC magnetic fields into epidemiological studies of EMF exposure. *Bioelectromagnetics* 14:413–431.
- Bowman JD, Thomas DC, London SJ, Peters JM (1995): Hypothesis: The risk of childhood leukemia may be related to combinations of power line frequency and static magnetic fields. *Bioelectromagnetics* 16:48–59.
- Feychting M, Ahlbom A (1992): Magnetic fields and cancer in people residing near Swedish high voltage power lines. IMM report 6/92, Karolinska Institute, Stockholm.
- Kaune WT, Zaffanella LE (1992): Analysis of magnetic fields produced far from electric power lines. *IEEE Transact Power Delivery* 7:2082–2091.
- Lednev VV (1991): Possible mechanism for the influence of weak magnetic fields on biological systems. *Bioelectromagnetics* 12:71–75.
- Liboff AR (1985): Geomagnetic cyclotron resonance in living cells. *J Biol Phys* 13:99–102.
- Liboff AR (1987): Cyclotron resonance effects at 60 Hz. U.S. Department of Energy Contractors Review Meeting, Kansas City.
- Liboff AR, McLeod BR, Smith SD (1989a): The physical basis for the ELF interaction with biological systems. In Wilson BW, Stevens RG, Anderson LE (eds): "Extremely Low Frequency Electromagnetic Fields: The Question of Cancer." Columbus, OH: Battelle Press, pp 251–289.
- Liboff AR, Thomas JR, Schrot J (1989b): Intensity threshold for 60-Hz magnetically induced behavioral changes in rats. *Bioelectromagnetics* 10:111–113.
- Liboff AR, Jenrow KA, McLeod BR (1993): ELF-induced proliferation at 511 mG in HSB-2 cell culture as a function of 60 Hz field intensity. In Blank M (ed): "Electricity and Magnetism in Biology and Medicine." San Francisco: San Francisco Press, pp 623–627.
- London SJ, Thomas DC, Bowman JD, Sobel E, Peters JM (1991): Exposure to residential electric and magnetic fields and risk of childhood leukemia. *Am J Epidemiol* 134:923–937.
- Peddie NW (1983): The magnetic field of the earth, 1990. Total intensity chart GP-1004-F, Denver Federal Center, CO 80225.
- Rozek RJ, Sherman ML, Liboff AR, McLeod BR, Smith SD (1987): Nifedipine is an antagonist to cyclotron resonance enhancement of ^{45}Ca incorporation in human lymphocytes. *Cell Calcium* 8:413–427.
- Savitz DA, Wachtel H, Barnes FA, John EM, Tvrdik JG (1988): Case-control study of childhood cancer and exposure to 60-Hertz magnetic fields. *Am J Epidemiol* 128:21–38.
- Smith SD, McLeod BR, Liboff AR, Cooksey K (1987): Calcium cyclotron resonance and diatom mobility. *Bioelectromagnetics* 8:215–227.
- Swanson J (1994): Measurements of static magnetic fields in homes in the UK and their implication for epidemiological studies of exposure to alternating magnetic fields. *J Radiol Protection* 14:67–75.
- U.S. Geological Survey (1985): The magnetic field in the United States. Charts GP-986D, GP-986F, GP-986I, Box 25046, MS 968, Denver Federal Center, CO 80225.
- Wertheimer N, Leeper E (1979): Electrical wiring configurations and childhood cancer. *Am J Epidemiol* 109:273–284.
- Wertheimer N, Leeper E, Wachtel H, Barnes F (1990): Angle of the magnetic field measurements in two existing studies of residential exposure. U.S. Department of Energy Contractors' Review Meeting, Denver.